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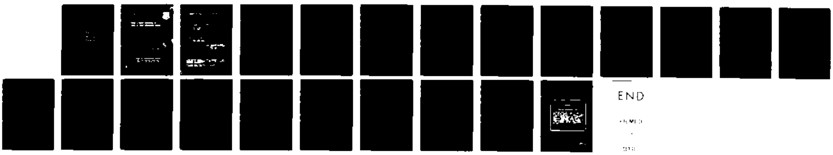

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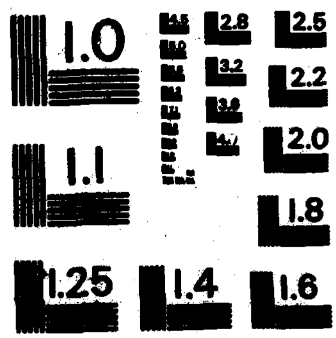

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RADC-TR-82-163
In-House Report
June 1982

PROBE ELEMENT MATCHING IN A PARALLEL-PLATE WAVEGUIDE ARRAY

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Griffiss Air Force Base, NY 13441

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Radar	Waveguide array

20. ABSTRACT (Continue on reverse side if necessary and identify by block

Voltage standing-wave ratio (VSWR) for a singly excited radiating probe element in a linear array in a parallel-plate waveguide is measured over the 8.0- to 10.0-GHz frequency band. The following parameters are varied: probe length, probe separation, and distance from probes to ground plane.

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Probe Element Matching in a Parallel-Plate Waveguide Array

1. INTRODUCTION

The objective of this work is to determine the voltage standing-wave ratio (VSWR) for a singly excited radiating coaxial probe element of a linear array in a parallel-plate waveguide as a function of three geometrical parameters: probe length, distance between probes and conducting ground plane, and probe separation. The results will be useful in the design of radiating elements for transverse electromagnetic wave (TEM) parallel-plate microwave lenses.

The model is comprised of a 5-element linear array in a parallel-plate waveguide. Figure 1 shows the cross section of the model. The flared end, as shown, simulates an infinite parallel plate waveguide. The location of the ground plane (part A in Figure 1) is adjustable in order to vary the ground plane distances. (For our experiment, g = 0.25, 0.328, 0.40, and 0.512 in.) Five top plates with different probe separations were used. The uniform distances between probes, therefore, may be adjusted to 0.680, 0.730, 0.850, 1.00, and 1.30 in. Five sets of probe lengths were also used: d = 0.625, 0.578, 0.50, 0.425, and 0.375 in.

The return loss (in decibels), that is, reflection coefficient (S_{11} parameter) of the center element of the array was measured, while the other four elements were terminated with 50-Ω loads. A schematic diagram of the measurement setup is shown in Figure 2. The test set was used in the reflection mode to measure the

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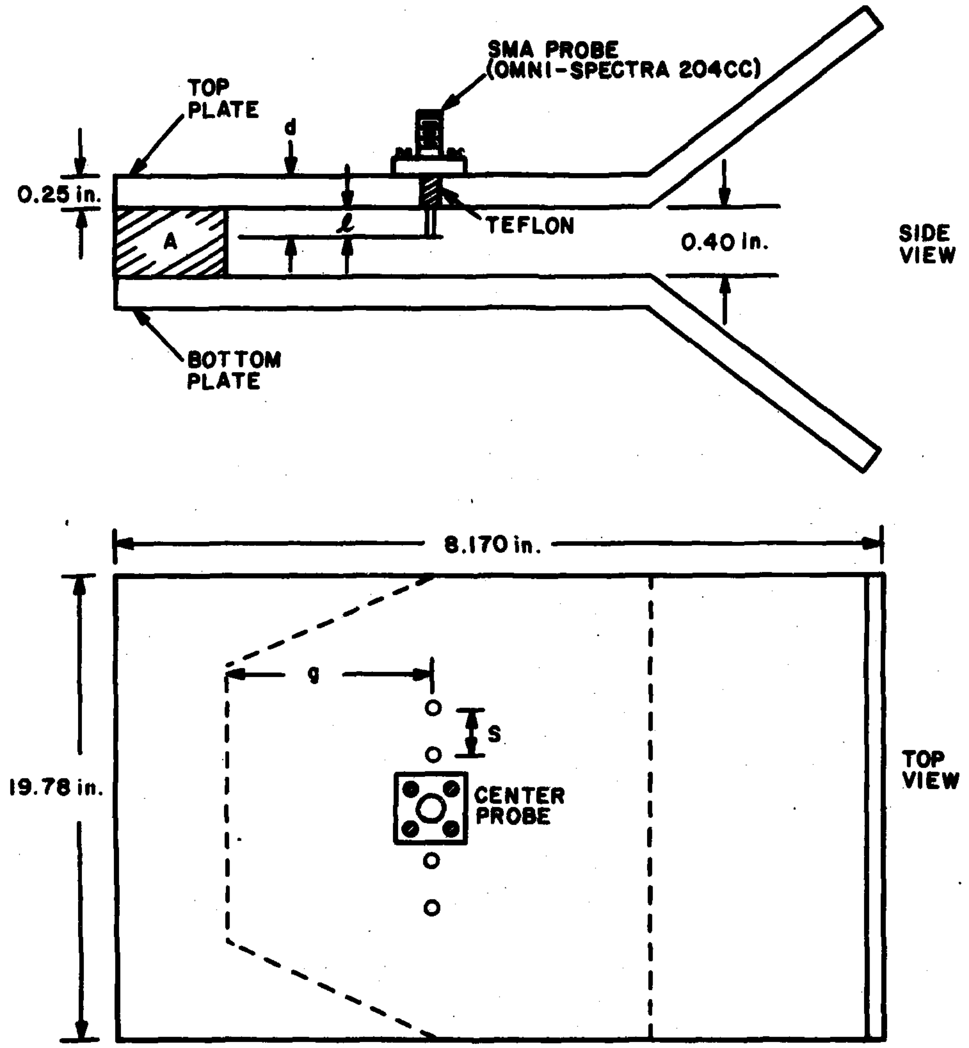


Figure 1. Experimental Model

power reflected from any mismatch in the center probe; a sweep oscillator was employed for making measurements over an 8.0- to 10.0-GHz frequency band. Five different ground plane distances, probe separations, and probe lengths were arranged in all combinations. The coaxial probes used in this experiment were type SMA, Flange Mount, Jack/Terminal.

In Table 1 we show the probe lengths, uniform probe spacing, and ground plane distances used in this experiment. The dimensions are given in inches and also normalized to free-space wavelength at 9 GHz (λ_0 = 1.3133 in.).

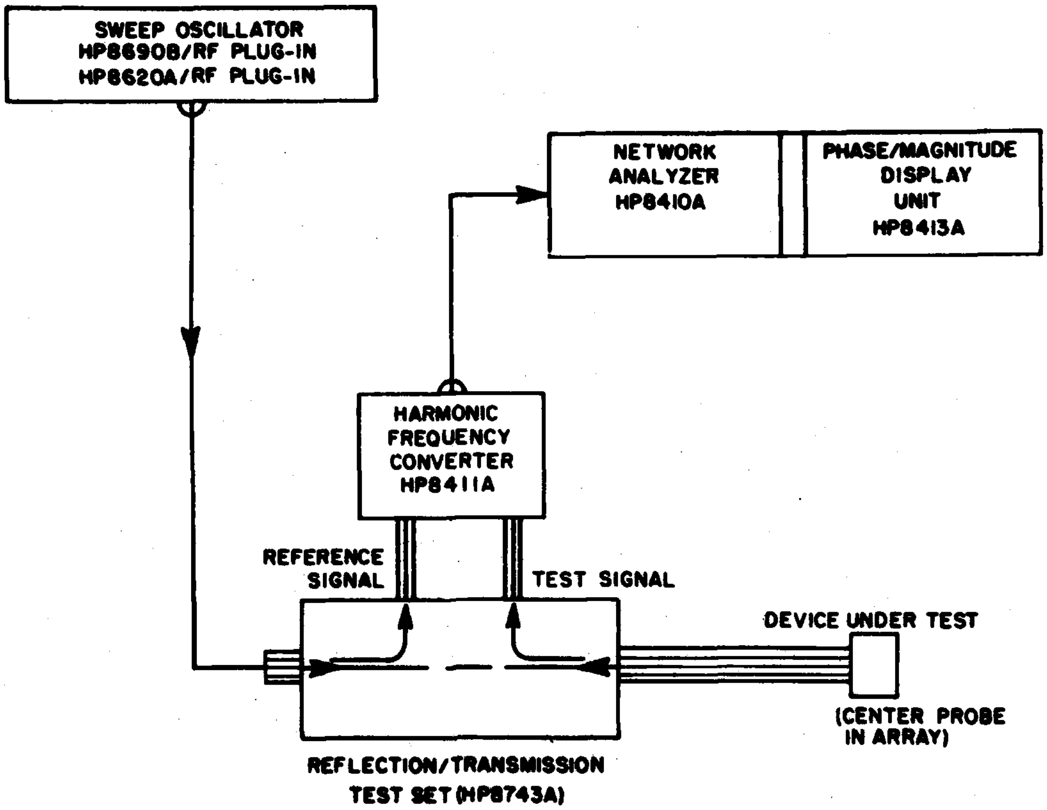


Figure 2. Schematic of Measurement Technique

Table 1. Model Parameters (λ_0 = 1.31 in. at 9.0 GHz)

Probe Length in Waveguide ℓ = d - 0.250		Ground Plane Distance		Probe Separation	
ℓ (in.)	ℓ/λ_0	g (in.)	g/λ_0	s (in.)	s/λ_0
0.375	0.286	0.175	0.133	0.680	0.518
0.328	0.250	0.250	0.190	0.730	0.556
0.250	0.190	0.328	0.250	0.850	0.648
0.175	0.133	0.400	0.305	1.000	0.763
0.125	0.095	0.512	0.390	1.300	0.992

2. MEASUREMENT DATA AND DISCUSSION

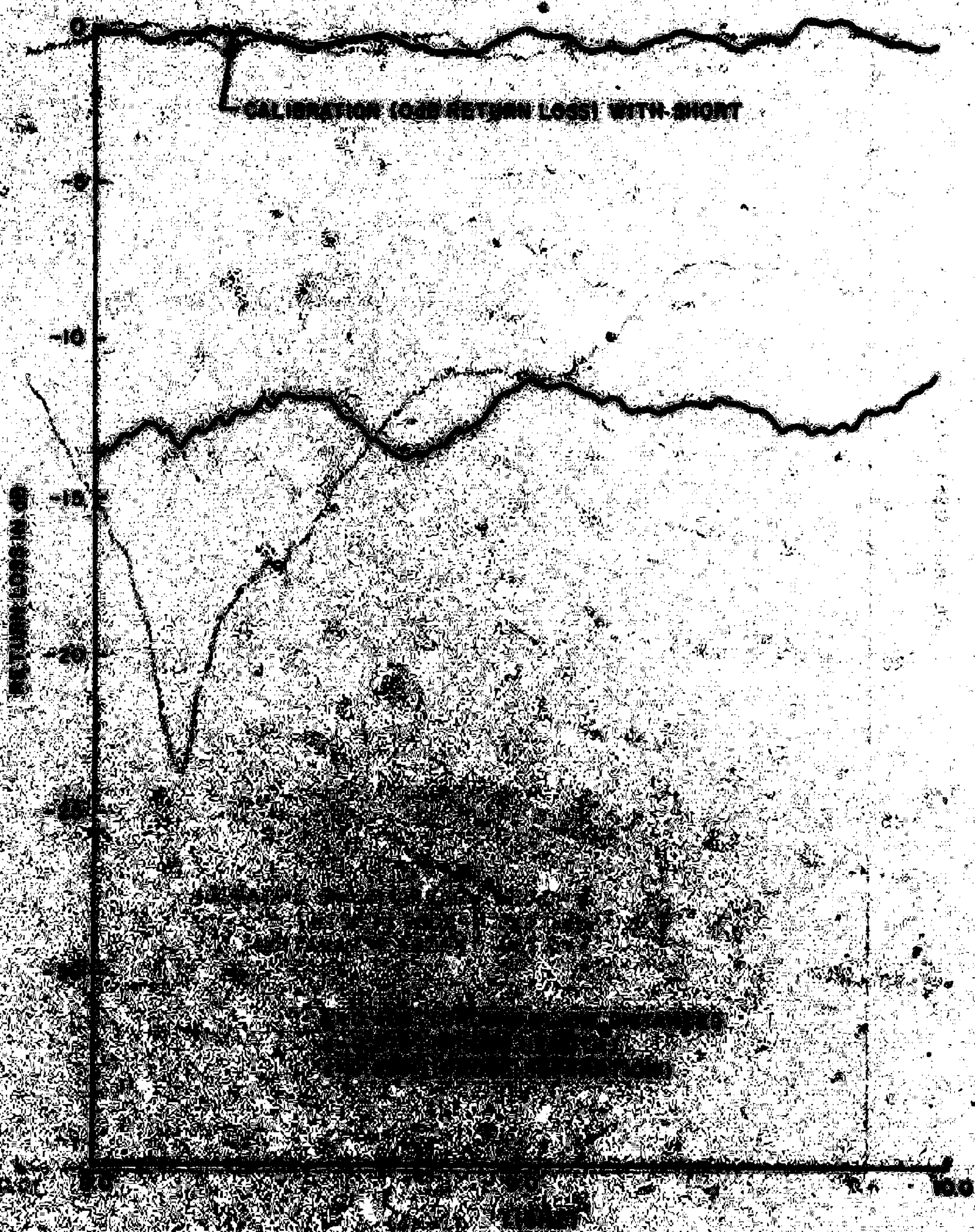
For the selected geometry (d = 0.578 in., s = 0.850 in., and g = 0.40 in.) measured return loss vs frequency is shown in Figure 3. Return loss was measured with respect to a short circuit termination; it is shown by a relatively flat curve. Observe that a 10 GHz, the maximum return loss is equal to -10.44 dB. This corresponds to a VSWR of 1.86. Moreover, one can see that the VSWR is approximately constant throughout the entire band and less than 1.86. Figure 4 shows good impedance matching (low return loss) for a narrow bandwidth between 9.0 and 10.0 GHz for d = 0.625 in., s = 0.730 in., and g = 0.512 in. Using the experimental data (return loss vs frequency graphs), we calculated the VSWR from

$$\mathrm{VSWR} = \frac{1 + 10^{RL/20}}{1 - 10^{RL/20}}$$

where RL is the return loss in decibels. Voltage standing-wave ratio was calculated for each of the three parameters: probe length (d), probe separation(s), and ground plane distance (g) at 8, 9, and 10 GHz. For all of the combinations of d, s, and g, we presented the measured return loss and calculated VSWR in Table 2 for the three frequencies. The order of presentation is as follows: d, then s, and finally g; for example, the first group of five is for d fixed at 0.375 in., s fixed at 0.680 in., and g varying through its five values. The next group of five is identical except that we move to the next value s, which is 0.730 in. In this manner, we present the data for all combinations of the model parameters.

Cases for VSWR less than 2.5 were first selected. From here, we noted a minimum value for VSWR = 1.40, corresponding to d = 0.578, s = 0.850, and g = 0.328 in. at 8 GHz. For these parameters (d, s, and g), Figures 5, 6, and 7 show VSWR vs s for 8, 9, and 10 GHz, respectively. The minimum VSWR was shown when g = 0.328 in., which corresponds to g/λ_0 = 0.25 at 9 GHz, as expected.

Probe length, however, turns out to be a critical parameter in element design (see Figures 13 to 17). Note the high VSWR for probe lengths less than 0.50 inch. Apparently, the shape of each individual curve (see Figures 8 to 12) changes but slightly as probe separations change. This is also seen in the plots for VSWR vs probe length.


CALIBRATION (0 dB RETURN LOSS) WITH SHORT
0
-10
-15
-20
10.0

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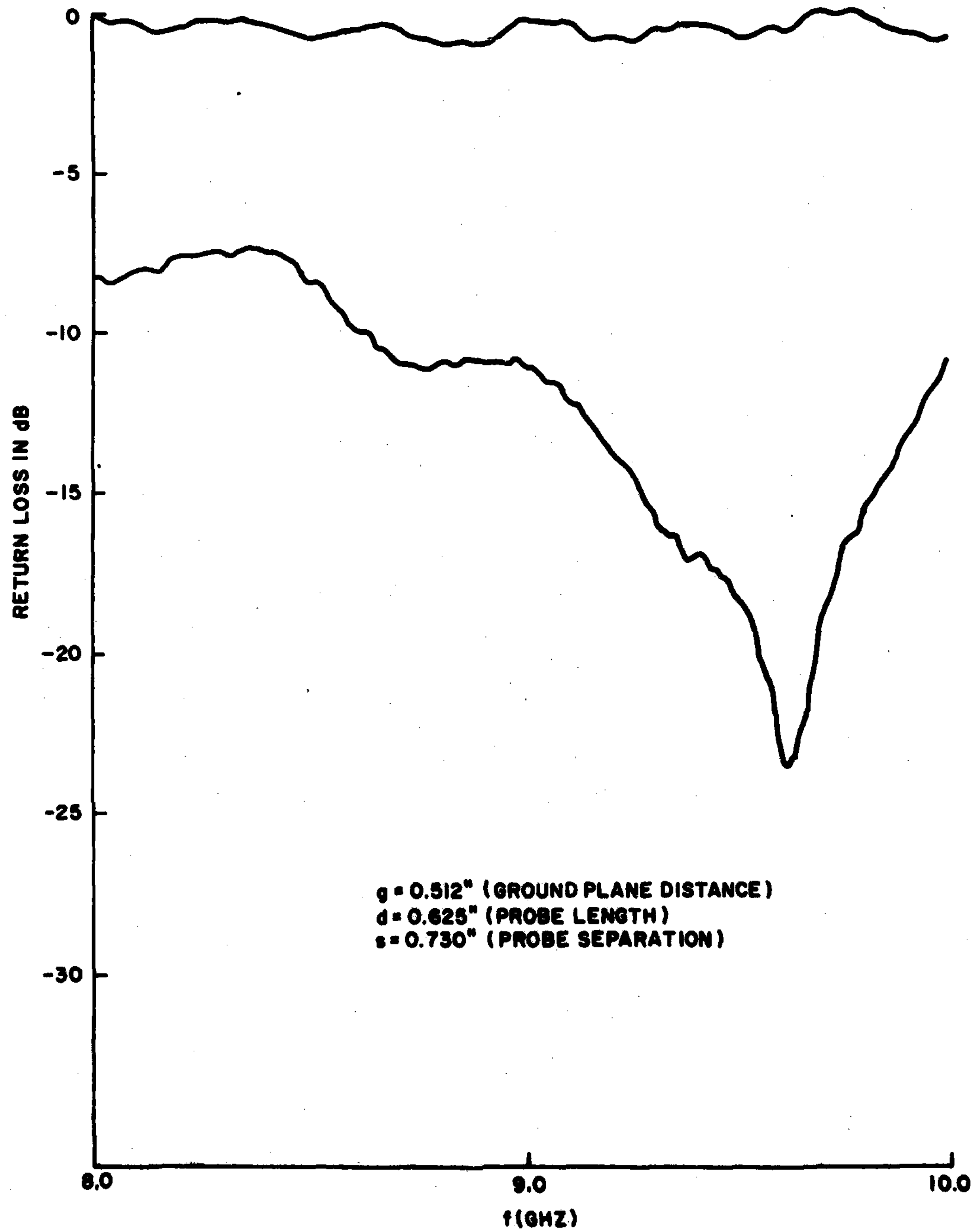

Figure 4. Return Loss vs Frequency (g = 0.512 in., s = 0.730 in., d = 0.625 in.)

Table 2. Return Loss and VSWR at 8, 9, and 10 GHz (d, s, and g are in inches)

			8 GHz		9 GHz		10 GHz	
d	s	g	RL	VSWR	RL	VSWR	RL	VSWR
0.375	0.680	0.175	-0.65	26.82	-1.98	8.81	-1.01	17.25
0.375	0.680	0.250	-0.54	32.18	-2.16	8.08	-0.72	24.14
0.375	0.680	0.328	-0.90	19.32	-2.52	6.94	-0.90	19.32
0.375	0.680	0.400	-0.90	19.32	-2.34	7.47	-1.08	16.11
0.375	0.680	0.512	-0.90	19.32	-2.70	6.49	-0.72	24.14
0.375	0.730	0.175	-0.72	24.14	-0.72	24.14	-0.72	24.14
0.375	0.730	0.250	-0.72	24.14	-0.90	19.32	-0.90	19.32
0.375	0.730	0.328	-0.90	19.32	-1.08	16.11	-0.90	19.32
0.375	0.730	0.400	-0.90	19.32	-1.26	13.81	-0.90	19.32
0.375	0.730	0.512	-1.08	16.11	-1.08	16.11	-0.72	24.14
0.375	0.850	0.175	-0.54	32.18	-0.54	32.18	-0.54	32.18
0.375	0.850	0.250	-0.72	24.14	-0.72	24.14	-0.72	24.14
0.375	0.850	0.328	-0.72	24.14	-1.08	16.11	-0.90	19.32
0.375	0.850	0.400	-0.83	21.00	-1.08	16.11	-0.83	21.00
0.375	0.850	0.512	-0.83	21.00	-0.90	19.32	-0.72	24.14
0.375	1.000	0.175	-0.65	26.82	-0.54	32.18	-0.54	32.18
0.375	1.000	0.250	-0.79	21.95	-0.90	19.32	-0.79	21.95
0.375	1.000	0.328	-0.79	21.95	-1.33	13.07	-0.94	18.58
0.375	1.000	0.400	-0.90	19.32	-0.90	19.32	-0.90	19.32
0.375	1.000	0.512	-0.72	24.14	-0.90	19.32	-0.72	24.14
0.375	1.300	0.175	-0.54	32.18	-0.54	32.18	-0.54	32.18
0.375	1.300	0.250	-0.72	24.14	-0.90	19.32	-0.90	19.32
0.375	1.300	0.328	-0.72	24.14	-1.15	15.10	-1.08	16.11
0.375	1.300	0.400	-0.72	24.14	-1.08	16.11	-0.90	19.32
0.375	1.300	0.512	-0.72	24.14	-0.90	19.32	-0.72	24.14
0.425	0.680	0.175	-1.08	16.11	-1.44	12.09	-2.52	6.94
0.425	0.680	0.250	-1.44	12.09	-2.52	6.94	-3.24	5.42
0.425	0.680	0.328	-1.80	9.69	-2.99	5.87	-3.24	5.42
0.425	0.680	0.400	-1.98	8.81	-2.70	6.49	-2.88	6.09
0.425	0.680	0.512	-1.80	9.69	-2.52	6.94	-1.80	9.69
0.425	0.730	0.175	-1.08	16.11	-1.62	10.75	-2.34	7.47
0.425	0.730	0.250	-1.44	12.09	-2.34	7.47	-3.35	5.25
0.425	0.730	0.328	-1.80	9.69	-2.70	6.49	-3.24	5.42
0.425	0.730	0.400	-1.98	8.81	-2.70	6.49	-2.52	6.94
0.425	0.730	0.512	-1.80	9.69	-1.98	8.81	-1.62	10.75
0.425	0.850	0.175	-0.90	19.32	-1.26	13.81	-1.98	8.81
0.425	0.850	0.250	-1.37	12.72	-2.16	8.08	-3.06	5.74
0.425	0.850	0.328	-1.62	10.75	-2.34	7.47	-3.06	5.74
0.425	0.850	0.400	-1.80	9.69	-2.52	6.94	-2.52	6.94
0.425	0.850	0.512	-1.62	10.75	-1.80	9.69	-2.16	8.08
0.425	1.000	0.175	-1.44	12.09	-1.62	10.75	-2.34	7.47
0.425	1.000	0.250	-1.80	9.69	-2.16	8.08	-3.06	5.74
0.425	1.000	0.328	-1.80	9.69	-2.52	6.94	-3.06	5.74
0.425	1.000	0.400	-1.80	9.69	-2.52	6.94	-3.42	5.14
0.425	1.000	0.512	-1.80	9.69	-2.52	6.94	-1.98	8.81

Table 2. Return Loss and VSWR at 8, 9, and 10 GHz (d, s, and g are in inches) (Contd)

			8 GHz		9 GHz		10 GHz	
d	s	g	RL	VSWR	RL	VSWR	RL	VSWR
0.425	1.300	0.175	-1.44	12.09	-2.34	7.47	-2.88	6.09
0.425	1.300	0.250	-1.44	12.09	-2.34	7.47	-3.42	5.14
0.425	1.300	0.328	-1.62	10.75	-2.52	6.94	-3.24	5.42
0.425	1.300	0.400	-1.80	9.69	-2.52	6.94	-2.88	6.09
0.425	1.300	0.512	-1.62	10.75	-1.98	8.81	-2.16	8.08
0.500	0.680	0.175	-4.50	3.95	-8.64	2.17	-16.02	1.38
0.500	0.680	0.250	-7.20	2.55	-15.30	1.41	-24.84	1.12
0.500	0.680	0.328	-8.64	2.17	-11.52	1.72	-12.60	1.61
0.500	0.680	0.400	-8.64	2.17	-8.28	2.25	-8.64	2.17
0.500	0.680	0.512	-6.86	2.73	-5.22	3.43	-4.68	3.80
0.500	0.730	0.175	-4.32	4.10	-8.82	2.14	-15.12	1.43
0.500	0.730	0.250	-7.20	2.55	-14.76	1.45	-29.16	1.07
0.500	0.730	0.328	-8.64	2.17	-10.98	1.79	-13.68	1.52
0.500	0.730	0.400	-7.92	2.34	-7.92	2.34	-9.36	2.03
0.500	0.730	0.512	-6.12	2.95	-4.86	3.67	-5.22	3.43
0.500	0.850	0.175	-3.96	4.46	-7.92	2.34	-13.50	1.54
0.500	0.850	0.250	-6.84	2.67	-12.60	1.61	-36.72	1.03
0.500	0.850	0.328	-14.76	1.45	-11.52	1.72	-16.20	1.37
0.500	0.850	0.400	-6.66	2.73	-5.04	3.54	-11.88	1.68
0.500	0.850	0.512	-5.04	3.54	-5.40	3.32	-8.28	2.25
0.500	1.000	0.175	-4.32	4.10	-7.92	2.34	-13.68	1.52
0.500	1.000	0.250	-6.48	2.80	-13.32	1.55	-36.72	1.03
0.500	1.000	0.328	-6.84	2.67	-11.52	1.72	-17.64	1.30
0.500	1.000	0.400	-6.12	2.95	-8.64	2.17	-13.32	1.55
0.500	1.000	0.512	-4.32	4.10	-6.12	2.95	-12.24	1.65
0.500	1.300	0.175	-4.32	4.10	-8.64	2.17	-13.68	1.52
0.500	1.300	0.250	-6.30	2.88	-14.40	1.47	-30.78	1.06
0.500	1.300	0.328	-7.20	2.55	-12.60	1.61	-15.12	1.43
0.500	1.300	0.400	-6.84	2.67	-10.08	1.91	-11.16	1.77
0.500	1.300	0.512	-5.58	3.22	-7.20	2.55	-7.38	2.49
0.578	0.680	0.175	-11.52	1.72	-8.10	2.30	-5.22	3.43
0.578	0.680	0.250	-21.96	1.17	-9.18	2.07	-7.20	2.55
0.578	0.680	0.328	-14.04	1.50	-10.08	1.91	-9.00	2.10
0.578	0.680	0.400	-18.72	1.26	-9.90	1.94	-11.34	1.74
0.578	0.680	0.512	-14.04	1.50	-9.00	2.10	-15.66	1.39
0.578	0.730	0.175	-10.08	1.91	-7.20	2.55	-5.31	3.37
0.578	0.730	0.250	-14.40	1.47	-8.64	2.17	-6.48	2.80
0.578	0.730	0.328	-14.04	1.50	-9.72	1.97	-8.10	2.30
0.578	0.730	0.400	-11.52	1.72	-10.08	1.91	-11.52	1.72
0.578	0.730	0.512	-9.00	2.10	-10.08	1.91	-20.52	1.21

Table 2. Return Loss and VSWR at 8, 9, and 10 GHz (d, s, and g are in inches) (Contd)

			8 GHz		9 GHz		10 GHz	
d	s	g	RL	VSWR	RL	VSWR	RL	VSWR
0.578	0.850	0.175	-11.16	1.77	-7.20	2.55	-5.40	3.32
0.578	0.850	0.250	-17.10	1.32	-8.82	2.14	-6.84	2.67
0.578	0.850	0.328	-15.48	1.40	-9.72	1.97	-7.92	2.34
0.578	0.850	0.400	-13.50	1.54	-11.16	1.77	-10.44	1.86
0.578	0.850	0.512	-10.08	1.91	-15.30	1.41	-8.82	2.14
0.578	1.000	0.175	-10.80	1.81	-6.30	2.88	-2.88	6.09
0.578	1.000	0.250	-14.94	1.44	-4.68	3.80	-3.42	5.14
0.578	1.000	0.328	-18.90	1.26	-9.18	2.07	-6.84	2.67
0.578	1.000	0.400	-16.92	1.33	-11.34	1.74	-7.92	2.34
0.578	1.000	0.512	-12.96	1.58	-21.60	1.18	-8.28	2.25
0.578	1.300	0.175	-10.26	1.89	-7.20	2.55	-8.64	2.17
0.578	1.300	0.250	-15.12	1.43	-7.74	2.39	-5.22	3.43
0.578	1.300	0.328	-17.64	1.30	-8.64	2.17	-7.20	2.55
0.578	1.300	0.400	-15.12	1.43	-9.18	2.07	-6.84	2.67
0.578	1.300	0.512	-18.54	1.27	-10.08	1.91	-14.76	1.45
0.625	0.680	0.175	-5.94	3.04	-4.14	4.28	-3.96	4.46
0.625	0.680	0.250	-6.48	2.80	-4.86	3.67	-3.96	4.46
0.625	0.680	0.328	-7.20	2.55	-5.58	3.22	-5.40	3.32
0.625	0.680	0.400	-7.74	2.39	-8.82	2.14	-7.74	2.39
0.625	0.680	0.512	-4.32	4.10	-9.18	2.07	-18.72	1.26
0.625	0.730	0.175	-6.05	2.99	-4.07	4.35	-3.13	5.61
0.625	0.730	0.250	-6.66	2.73	-4.86	3.67	-4.14	4.28
0.625	0.730	0.328	-7.20	2.55	-5.58	3.22	-5.22	3.43
0.625	0.730	0.400	-7.74	2.39	-6.84	2.67	-7.56	2.44
0.625	0.730	0.512	-8.10	2.30	-10.80	1.81	-9.72	1.97
0.625	0.850	0.175	-6.48	2.80	-3.78	4.67	-3.42	5.14
0.625	0.850	0.250	-7.58	2.44	-4.75	3.75	-3.96	4.46
0.625	0.850	0.328	-10.08	1.91	-7.02	2.61	-5.22	3.43
0.625	0.850	0.400	-10.08	1.91	-7.56	2.44	-6.12	2.95
0.625	0.850	0.512	-13.32	1.55	-14.40	1.47	-5.94	3.04
0.625	1.000	0.175	-6.48	2.80	-3.60	4.89	-3.42	5.14
0.625	1.000	0.250	-7.56	2.44	-4.50	3.95	-3.78	4.67
0.625	1.000	0.328	-8.82	2.14	-5.40	3.32	-4.50	3.95
0.625	1.000	0.400	-10.08	1.91	-6.48	2.80	-5.04	3.54
0.625	1.000	0.512	-15.18	1.40	-9.54	2.00	-5.40	3.32
0.625	1.300	0.175	-6.12	2.95	-3.78	4.67	-3.06	5.74
0.625	1.300	0.250	-6.84	2.67	-4.50	3.95	-3.96	4.46
0.625	1.300	0.328	-7.20	2.55	-5.22	3.43	-4.68	3.80
0.625	1.300	0.400	-7.56	2.44	-5.94	3.04	-6.12	2.95
0.625	1.300	0.512	-8.46	2.21	-7.56	2.44	-10.08	1.91

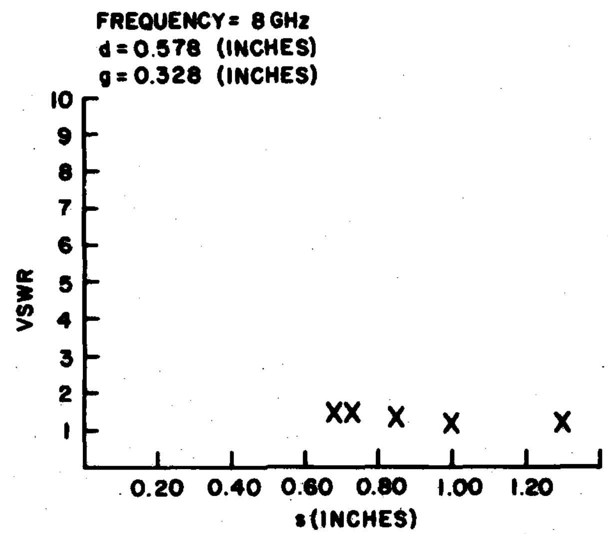

Figure 5. VSWR vs Probe Separation (f = 8 GHz, d = 0. 578 in., g = 0.328 in.)

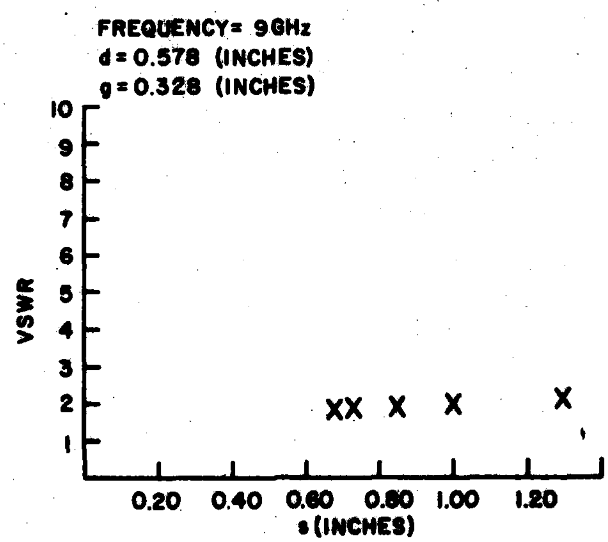

Figure 6. VSWR vs Probe Separation (f = 9 GHz, d = 0. 578 in., g = 0. 328 in.)

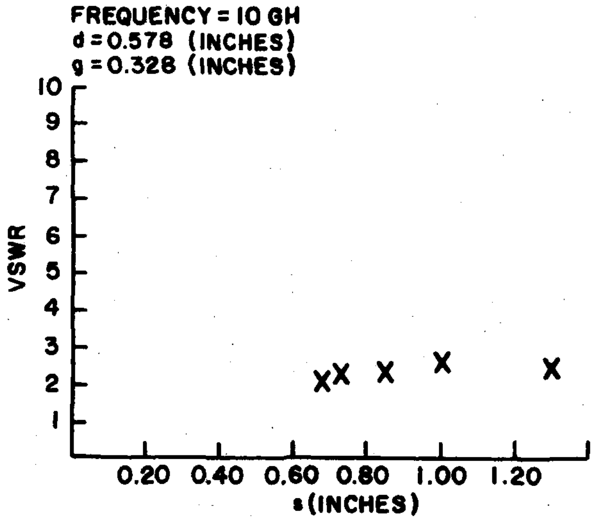

Figure 7. VSWR vs Probe Separation (f = 10 GHz, d = 0.578 in., g = 0.328 in.)

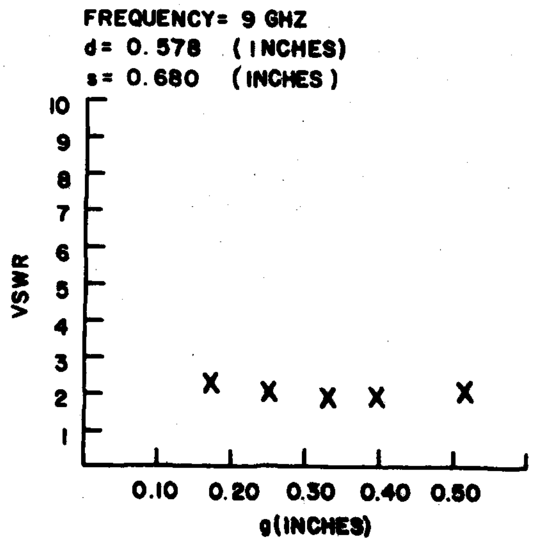

Figure 8. VSWR vs Ground Plane Distance (f = 9 GHz, d = 0.578 in., s = 0.680 in.)

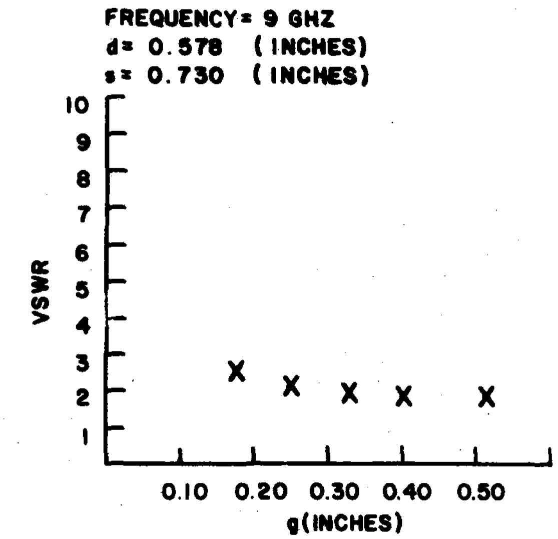

Figure 9. VSWR vs Ground Plane Distance (f = 9 GHz, d = 0.578 in., s = 0.730 in.)

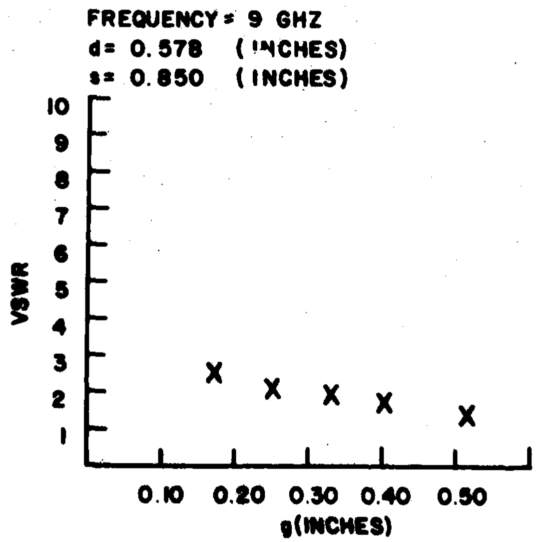

Figure 10. VSWR vs Ground Plane Distance (f = 9 GHz, d = 0.578 in., s = 0.850 in.)

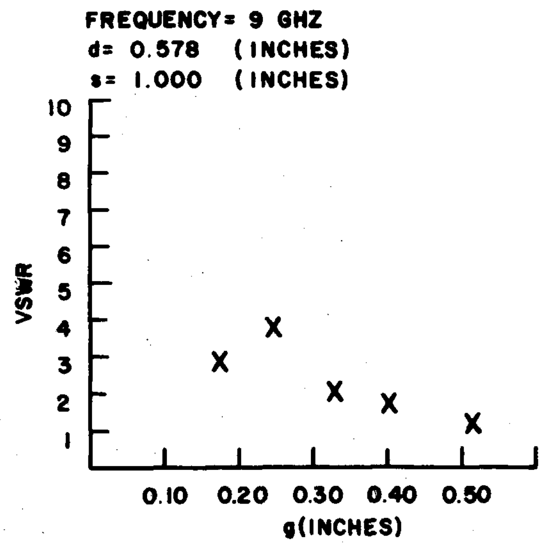

Figure 11. VSWR vs Ground Plane Distance (f = 9 GHz, d = 0.578 in., s = 1.00 in.)

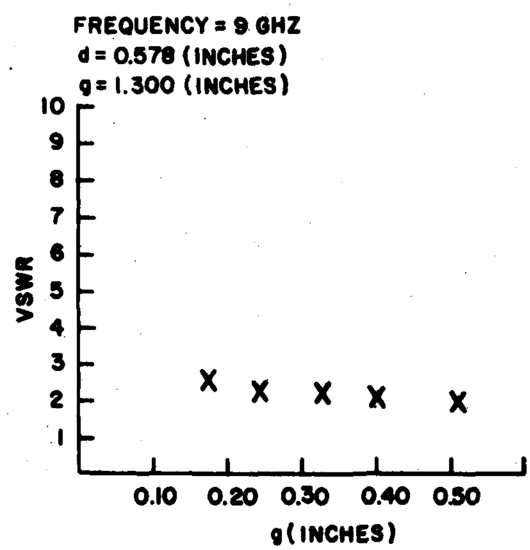

Figure 12. VSWR vs Ground Plane Distance (f = 9 GHz, d = 0.578 in., s = 1.30 in.)

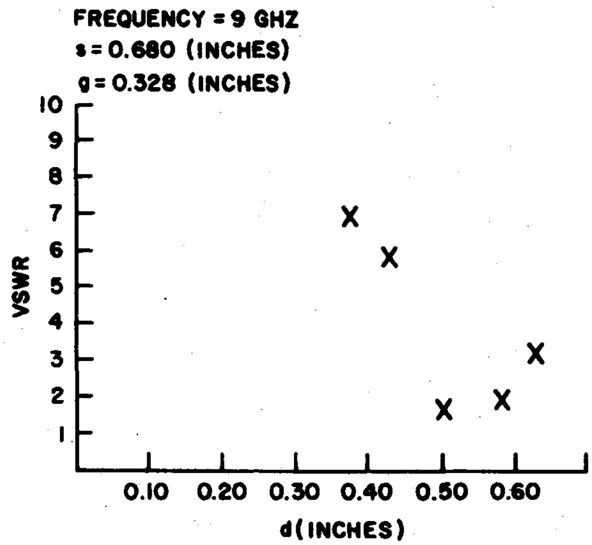

Figure 13. VSWR vs Probe Length (f = 9 GHz, s = 0.680 in., g = 0.328 in.)

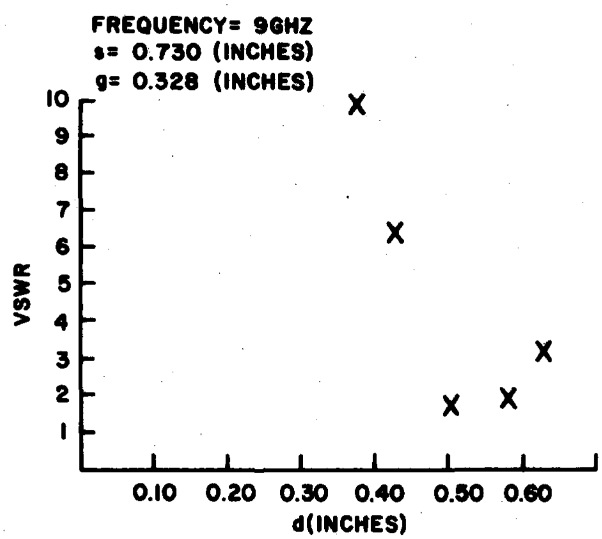

Figure 14. VSWR vs Probe Length (f = 9 GHz, s = 0.730 in., g = 0.328 in.)

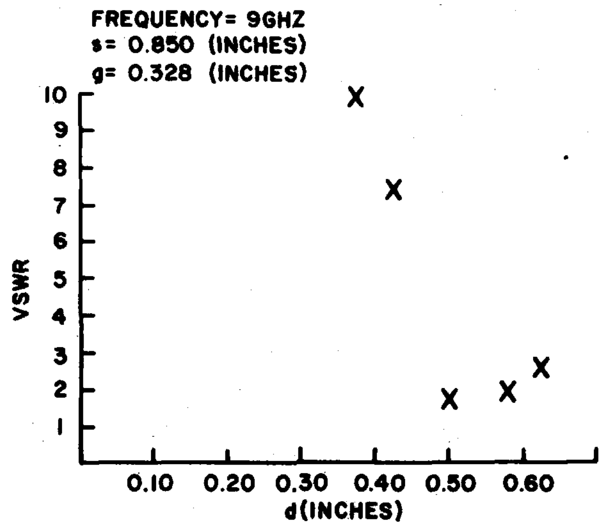

Figure 15. VSWR vs Probe Length (f = 9 GHz, s = 0.850 in., g = 0.328 in.)

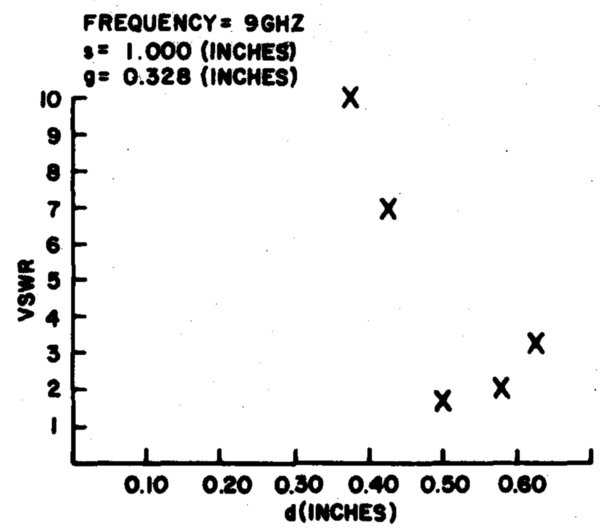

Figure 16. VSWR vs Probe Length (f = 9 GHz, s = 1.00 in., g = 0.328 in.)

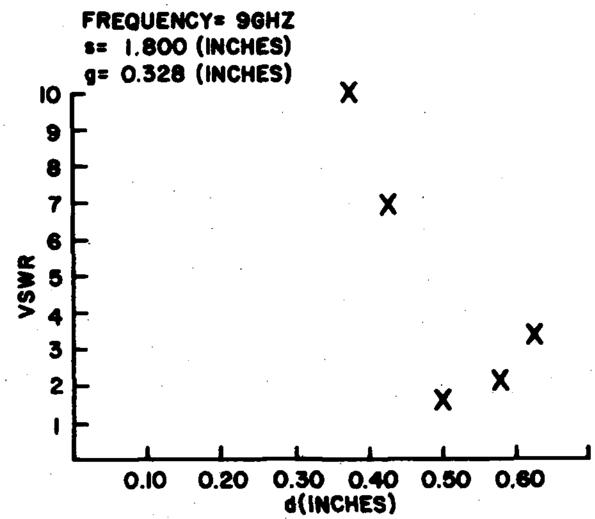

Figure 17. VSWR vs Probe Length (f = 9 GHz, s = 1.80 in., g = 0.328 in.)

3. CONCLUSIONS

According to our measurements, the VSWR for a singly excited probe element in a linear array in a parallel-plate waveguide is less than 2.34 when probe separation is 0.850 in., ground plate distance 0.328 in., and probe length 0.578 in. within the 8- to 10-GHz frequency band. Furthermore, the VSWR is fairly independent of probe separation and ground plane distance for the desired frequency band. However, it is very dependent on probe length. The return loss and VSWR have been presented for a large number of array parameters.

It should be noted that the reflection coefficient determined in the foregoing manner (S_{11} parameter) is not truly an "active reflection coefficient." An active reflection coefficient would require the simultaneous excitation of all the array probes and therefore would include mutual coupling effects. Moreover, the active reflection coefficient would be different for different phase progressions (linear phase tapers) across the array element probes; for example, different phase progressions would result from different angles of arrival of a plane wave onto the array of elements. The S_{11} measurement, however, as described in this report, can provide a useful starting point for more sophisticated probe matching techniques. Future studies should address the active impedance matching problem.